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RESEARCH MEMORANDUM

EVALUATION OF AN AUTOMATIC INLET-PRESSURE CONTROL VALVE FOR STUDY OF TRANSIENT ENGINE PERFORMANCE CHARACTERISTICS

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EVALUATION OF AN AUTOMATIC INLET-PRESSURE CONTROL VALVE FOR STUDY OF TRANSIENT ENGINE PERFORMANCE CHARACTERISTICS

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SUMMARY

An evaluation of data obtained with an automatic constant inlet-pressure control valve designed to facilitate the study of transient engine performance characteristics was made in the Lewis altitude wind tunnel. In this evaluation, engine characteristics obtained by use of the pressure valve were compared with those obtained with a bellmouth inlet operating in simulated free-stream conditions.

The constant-inlet-pressure valve was operated with a proportional-type and a proportional-plus-integral control. During acceleration, inlet total-pressure deviations of about 5 percent from the desired level were obtained with the proportional-type control. When integrating action was added to the control, this pressure deviation was reduced to $1\frac{1}{2}$ percent. Furthermore, the engine transient and surge characteristics obtained with the automatic inlet-pressure valve were about the same as those obtained with the bellmouth-inlet installation.

INTRODUCTION

In studying the altitude operational characteristics of a turbojet engine, large and rapid accelerations must be made to determine the engine surge limits, combustion blow-out limits, and transient control operation. In order to obtain accurate data of this type in an altitude test facility, it is important that the inlet and exhaust pressures be maintained at the desired altitude. This becomes a very difficult condition to satisfy during large accelerations when the engine air-flow requirements increase by a factor of 2 to 3. Because the air-handling machinery servicing these test facilities has very high inertia and thus is slow-acting, it cannot satisfy such transient air-flow demands. Also, it is impossible to follow the transient air-flow demand with sufficient speed by adjusting the air control valves of the test facility.

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In view of the limitations of the facility equipment for transient operation, a high-response automatic valving system was developed at the NACA Lewis laboratory by Harold Gold and Edward Otto for use in the several engine altitude test chambers. This automatically controlled inlet-pressure valve, subsequently referred to as the "ram valve," is placed in the inlet duct several feet upstream of the engine inlet. In operating with this system, the facility controls are set to provide the maximum engine air requirement during a particular transient. The excess over that required by the engine at any time during the transient is bypassed around the engine by the ram valve, which is controlled to maintain engine-inlet total pressure essentially constant.

This report demonstrates the validity of transient engine performance obtained with such an automatic inlet-pressure control valve. Transient and steady-state characteristics of a turbojet engine with the ram valve were investigated in the Lewis altitude wind tunnel. Similar data were also obtained with the air being drawn into the engine through a bellmouth inlet from the test section of the tunnel. Because of the large air volume of the altitude wind tunnel (about 650,000 cu ft), engine transients made with this configuration result in no measurable change in engine-inlet pressure, and thus can be considered equivalent to free-stream flight conditions. Transient data used herein were obtained at altitudes between 15,000 and 50,000 feet and at flight Mach numbers between 0.2 and 0.8. The comparison between bellmouth and ram-valve operation is shown in terms of engine acceleration, fuel-flow stall limits, compressor-pressure-ratio stall limits, and engine surge characteristics.

APPARATUS

An axial-flow turbojet engine of approximately 10,000-pound-thrust (air flow, about 160 lb/sec) was used in this study. Steady-state and transient instrumentation installed at each of the measuring stations is shown in figure 1. The transient data were recorded on multiple-channel oscillographs. Pressure variations were measured by means of pressure transducers, which converted pressure changes into electrical signals for input into the oscillograph after appropriate amplification. Engine speed was measured with a high-speed electronic counter. The engine was equipped with a special fuel control that maintained constant pressure drop across the throttle. As a result, it was possible to use throttle position as an indication of fuel flow.

Automatic Inlet-Pressure Valve Configuration

A schematic drawing of the ram-valve system and its major components is shown in figure 2; a photograph of the installation is presented in figure 3. The action of the ram valve allows the slow-acting facility air supply and exhaust system to remain at essentially constant flow conditions during changing engine air requirements. This is accomplished by decreasing the amount of bypass air as the engine air-flow requirement increases during acceleration. The reverse process occurs during deceleration. The amount of bypass air is controlled by eight equally spaced ports around the circumference of the inlet duct (bleed valves). One port is directly connected to the servomotor; the remaining ports are actuated through a chain linkage.

The prime consideration in the design of the ram-valve system was fast response. To accomplish this, a two-stage electro-hydraulic servomotor having a fast response and a high torque output was designed and built. Special care was taken in the design of the bleed valves and drive to keep the inertia as low as possible within structural limitations. Data on the design procedure of the valve and control systems are not yet published. However, data on the design of the servomotor are published in references 1 and 2. For the configuration considered herein, the over-all time constant of the servomotor with the bleed valves was about 0.05 second.

Engine air was supplied through the ram pipe from the tunnel make-up air system. The manually operated throttle valve, which controls the engine-inlet pressure, is adjusted to give the desired engine-inlet pressure prior to engagement of the automatic ram-valve system. The pressure-sensing probe senses engine-inlet total pressure.

The pressure transducer converts the difference between the existing pressure at the engine inlet and the reference pressure (desired pressure set up during initial steady-state conditions) to an electrical signal proportional to the difference (error). Loading the reference side of the pressure transducer to the desired inlet pressure is accomplished by the solenoid valve. The output signal of the control is then a function of the input error signal. Both a proportional control and a proportional-plus-integral control were used. The maximum value of control gain setting was dictated by stability considerations; that is, increasing the gain would decrease the deviation of total pressure from the value desired, but too high a gain would result in system instability. A two-stage electro-hydraulic servomotor converts the signal from the controller to a shaft movement.

Bellmouth Configuration

The engine was operated in the altitude wind tunnel with a bellmouth inlet as a means of comparison with the ram valve. Because the tunnel volume is very large in comparison with engine air requirements (about 650,000 cu ft), this mode of operation simulates an engine running in free-stream conditions. The bellmouth was an A.S.M.E. design and was directly connected to a 24-inch instrumentation section, which in turn was connected to the engine-inlet flange.

PROCEDURE

Steady-state data were obtained with the two engine-inlet configurations at altitudes between 15,000 and 50,000 feet at flight Mach numbers between 0.2 and 0.8. Because of tunnel limitations, operation with the bellmouth inlet could only be obtained in the low Mach number range. At each flight condition the engine was operated over the full speed range, and comprehensive pressure and temperature measurements were made at all the instrumentation stations indicated in figure 1. The steady-state data were required to determine any possible inlet-flow distortion effects arising from the ram-valve installation. Step increases in fuel flow were introduced into the engine to study any possible effects on acceleration characteristics, such as fuel-flow surge limits, compressor-pressure-ratio surge limits, engine time constants, and surge pressure amplitude and frequency.

RESULTS AND DISCUSSION

Before transient engine operation is considered with the automatically controlled inlet-pressure valve, it should be determined whether steady-state operation with the valve is comparable with free-stream conditions. Operation of the engine with a bellmouth inlet in the altitude wind tunnel very closely duplicates operation in flight with no engine-inlet-flow distortion present. Steady-state data with the bellmouth inlet are compared to the data obtained with the automatic inlet-pressure valve in figures 4 and 5. Inlet velocity distributions are shown across the compressor-inlet annulus in figure 4. The local velocities for the two configurations are very similar, with the maximum local variation being about 3 percent. This velocity gradient is considerably less than 1 percent of the total pressure. The data in reference 3, obtained on a different engine, show that distortions of this magnitude had negligible effects on engine performance. Engine air-flow and exhaust-gas-temperature data are compared in figure 5. The same curve fits the data for both the bellmouth and the ram-valve configurations. It is clear then that the use of the ram-pipe - ram-valve combination does not influence the validity of steady-state engine data.

Engine Transients

Oscillograph traces of engine speed, fuel flow, and compressor inlet and outlet pressure are shown in figure 6 for typical accelerations with the bellmouth inlet and with the ram valve. The arrows on the trace indicate the increasing direction of each parameter. Two traces are shown for the inlet valve: one using a proportional control and the other using a proportional-plus-integral control. A 28-percent increase in fuel flow resulted in an ultimate speed increase of 20 percent without any change in compressor-inlet pressure for the engine with the bellmouth inlet drawing air from the large-capacity altitude wind tunnel (fig. 6(a)). A similar acceleration with the proportional-control ram valve resulted in a continual decrease in inlet pressure during the entire acceleration with a 3-percent inlet-pressure drop after about 7 seconds (fig. 6(b)). Other accelerations with the proportionally controlled valve resulted in pressure deviations of as much as 7 percent. For an acceleration with the proportional-plus-integral control (fig. 6(c)), the inlet-pressure deviation was negligible.

Inlet-pressure deviations are shown directly in figure 7 as a function of time for several accelerations with the proportional-control inlet valve. As is typical with all proportional-type controls, the maximum error (inlet-pressure deviation) occurs as the final equilibrium condition is approached. This maximum deviation in inlet pressure is related to the initial speed, change in engine speed, and the flight condition. The ratio of the final maximum inlet-pressure deviation to the speed change is presented as a function of initial speed in figure 8 for three flight conditions. The data shown here are for operation with the highest value of proportional gain possible within stability limits at the respective flight conditions. As inlet pressure was reduced, the pressure deviation for a given speed change increased. This increase probably arises because, as the absolute air pressure decreases, a larger percentage change in pressure is required to send a given signal to the actuator motor.

The pressure deviations for three typical accelerations using the proportional-plus-integral control are shown in figure 9. The maximum inlet-pressure deviation is $1\frac{1}{2}$ percent and occurs about 2 seconds after the fuel input. After a few more seconds the deviation is reduced to almost zero. Decreasing the inertia of the valving system makes it possible to increase the value of proportional gain used and still remain stable, thereby decreasing the initial deviation still further. Equipping the proportional control with integrating action for all practical purposes eliminates inlet-pressure deviations even for large and rapid accelerations.

All the succeeding data on surge acceleration characteristics have been obtained with the ram valve equipped with the proportional control. Data with integrating action added to the proportional control were not obtained. However, it has been demonstrated that inlet-pressure deviations were reduced markedly with the addition of integrating action. Therefore, any small effects that may be obtained with the proportional control would be lessened considerably by the use of the proportional-plus-integral control.

Surge Limits

Engine surge limits in terms of compressor pressure ratio and engine fuel flow are shown in figure 10 for the ram-valve and bellmouth installation. Both the steady-state and compressor stall data for the two configurations interplot with a good degree of consistency. This is also true of the steady-state fuel-flow data (fig. 10(b)). Considerable scatter occurs in the fuel-flow stall data, but this scatter is typical for data of this type. Examination of these surge data thus indicates no consistent difference between the results obtained with the bellmouth and the ram valve. Therefore, the ram valve maintains the inlet pressure sufficiently constant during transient operation to provide engine stall limits representative of those obtained with free-stream flow entering the inlet duct. 3966

Acceleration

A simple yet accurate measure of the acceleration capabilities of an engine is the engine time constant, which is the time required to attain 63.3 percent of the net change in speed. Time constants for the two inlet configurations are plotted as a function of speed in figure 11. The curve drawn for this data fits the bellmouth and the controlled-pressure valve equally well, indicating that acceleration data obtained with the ram valve are also representative of that obtained with free-stream flow in the inlet duct.

Surge Characteristics

During the course of the acceleration study, many fuel steps were made which were sufficiently large to cause engine surge, as shown by the data of figure 10. When surging commenced, no change was made in the engine fuel flow until a natural recovery, exhaust temperature limit, or combustion blow-out occurred. In this way, it was possible to determine the time for surge recovery, amplitude of the pressure oscillations, and surge frequencies for both inlet configurations. These comparisons are shown in figure 12. These data show that the time for surge recovery, amplitude of pressure oscillations, and surge frequencies are comparable for both inlet configurations. Although this agreement exists, it was demonstrated in reference 4 that variations in inlet-duct length did affect engine surge characteristics. It is conceivable, then, that the inlet configuration used in conjunction with a ram valve might influence the engine surge characteristics.

SUMMARY OF RESULTS

An automatic constant inlet-pressure control valve designed for the study of transient engine performance characteristics was evaluated in the Lewis altitude wind tunnel. This valve was operated with a proportional and a proportional-plus-integral type control. During acceleration, maximum inlet total-pressure deviations between 3 and 7 percent were obtained with the proportional-type control. Adding
3966 integrating action to the control reduced the deviation to $1\frac{1}{2}$ percent.

The engine transient data obtained indicate that the fuel-flow surge limits, pressure-ratio surge limits, acceleration characteristics, and the surging characteristics were essentially the same with the ram valve as with the bellmouth-inlet installation.

It is thus demonstrated that the automatic inlet-pressure valve is an effective tool that permits a valid simulation of free-stream engine transient operation in a limited volume test facility.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 13, 1955

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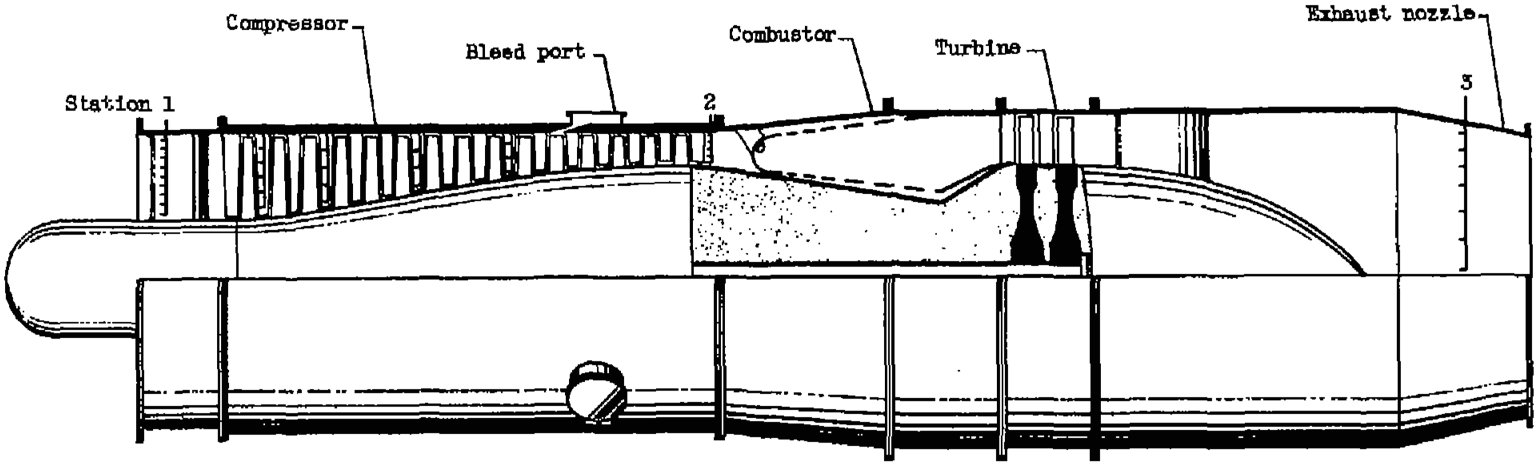
1. Gold, Harold, Otto, E. W., and Ransom, V. L.: An Analysis of the Dynamics of Hydraulic Servomotors Under Inertia Loads and the Application to Design. Trans. A.S.M.E., vol. 75, no. 7, Oct. 1953, pp. 1383-1394.

2. Gold, Harold, Otto, Edward W., and Ransom, Victor L.: Dynamics of Mechanical Feedback-Type Hydraulic Servomotors Under Inertia Loads. NACA Rep. 1125, 1953. (Supersedes NACA TN 2767.)

3. Conrad, E. William, and Sobolewski, Adam E.: Investigation of Effects of Inlet-Air Velocity Distortion on Performance of Turbojet Engine. NACA RM E50G11, 1950.

4. Lubick, Robert J., Chelko, Louis J., and Wallner, Lewis E.: Effect of Inlet-Duct Length on Turbojet-Engine Operation. NACA RM E55K15, 1956.



Instrumentation

Measured quantity	Station	Steady-state	Transient
Inlet total pressure	1	Manometer	Strain-gage pressure transducer
Compressor-outlet total pressure	3	Manometer	Strain-gage pressure transducer
Engine speed	-	Electronic counter	Electronic counter
Fuel flow	-	Rotameter	Throttle position (constant pressure drop)

Number of probes

Station	Total pressure	Static pressure	Thermocouple
1	42	16	16
2	20	0	12
3	24	4	24

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Figure 1. - Schematic diagram of turbojet engine showing location and amount of instrumentation.

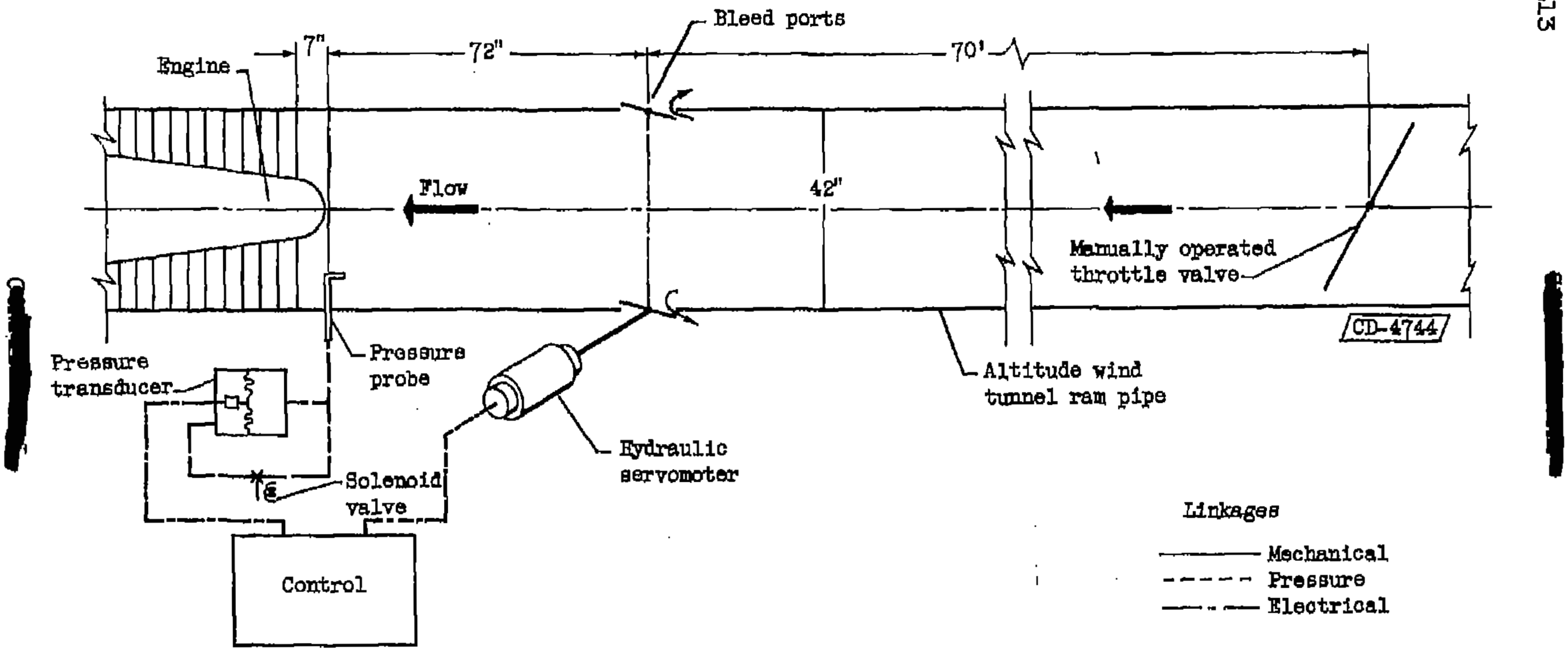


Figure 2. - Schematic drawing of automatic inlet-pressure control.

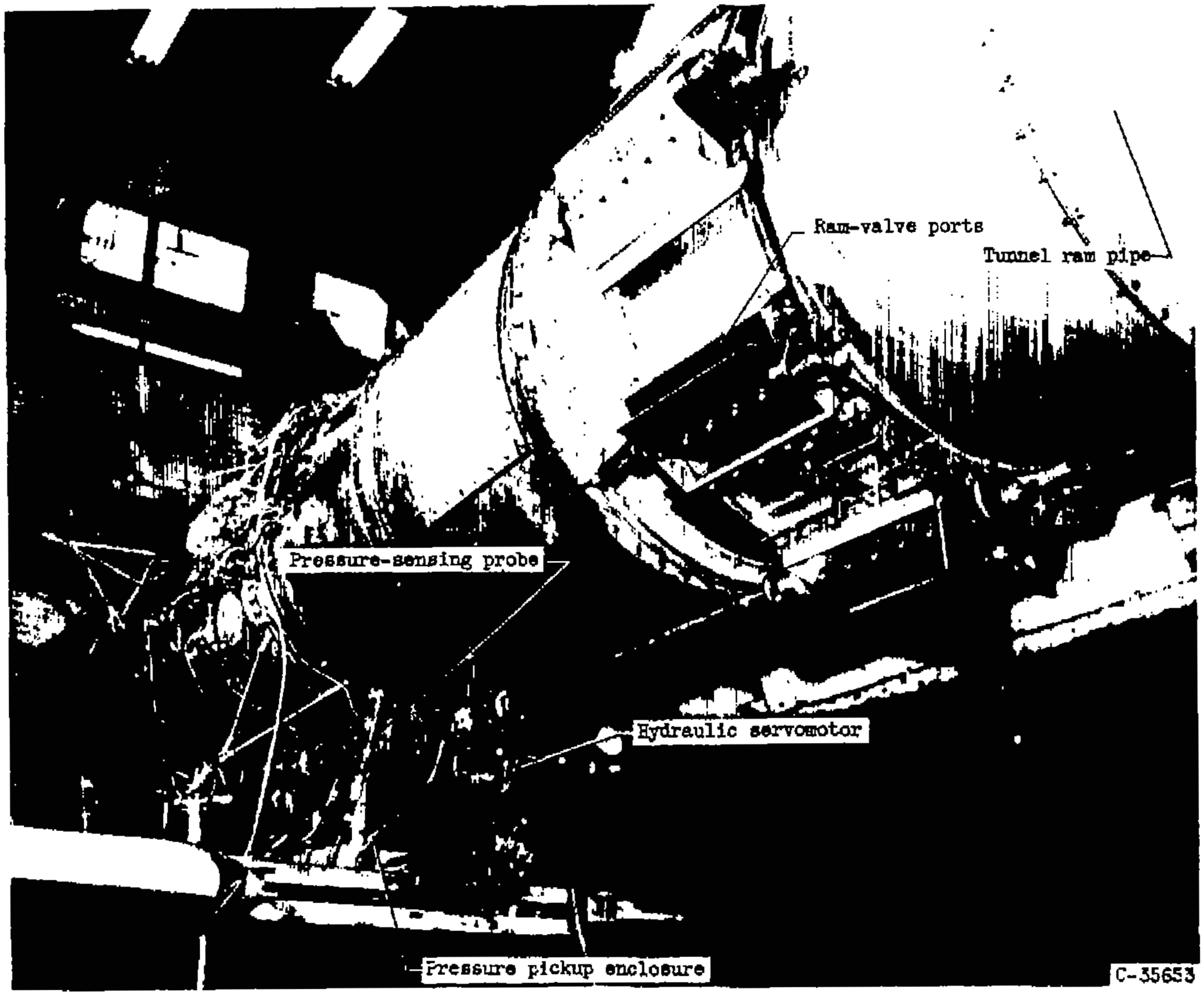
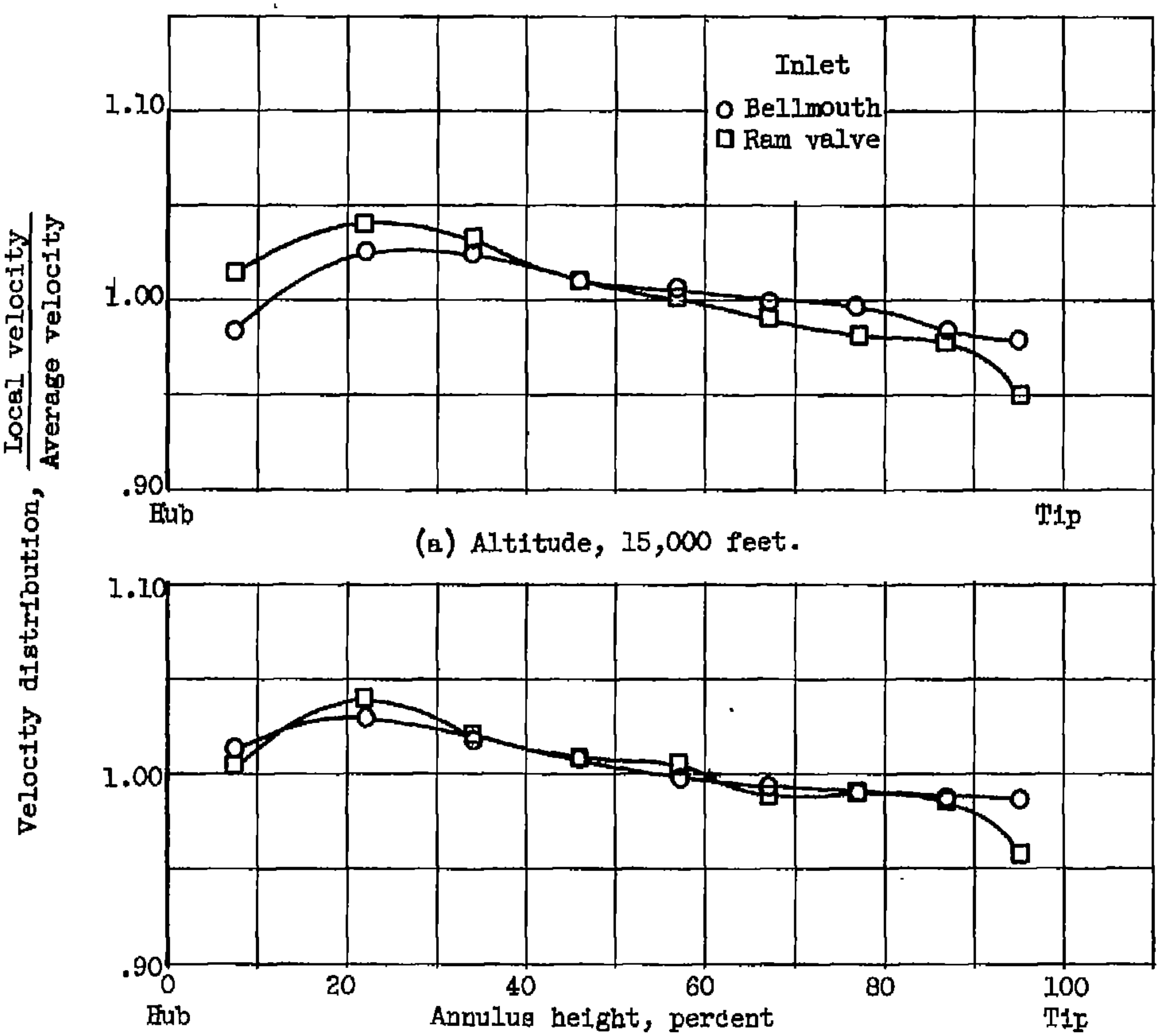


Figure 3. - Automatic inlet-pressure valve and control installed in altitude wind tunnel.



(b) Altitude, 50,000 feet.

Figure 4. - Effect of inlet configuration on engine-inlet velocity distribution. Flight Mach number, 0.2.

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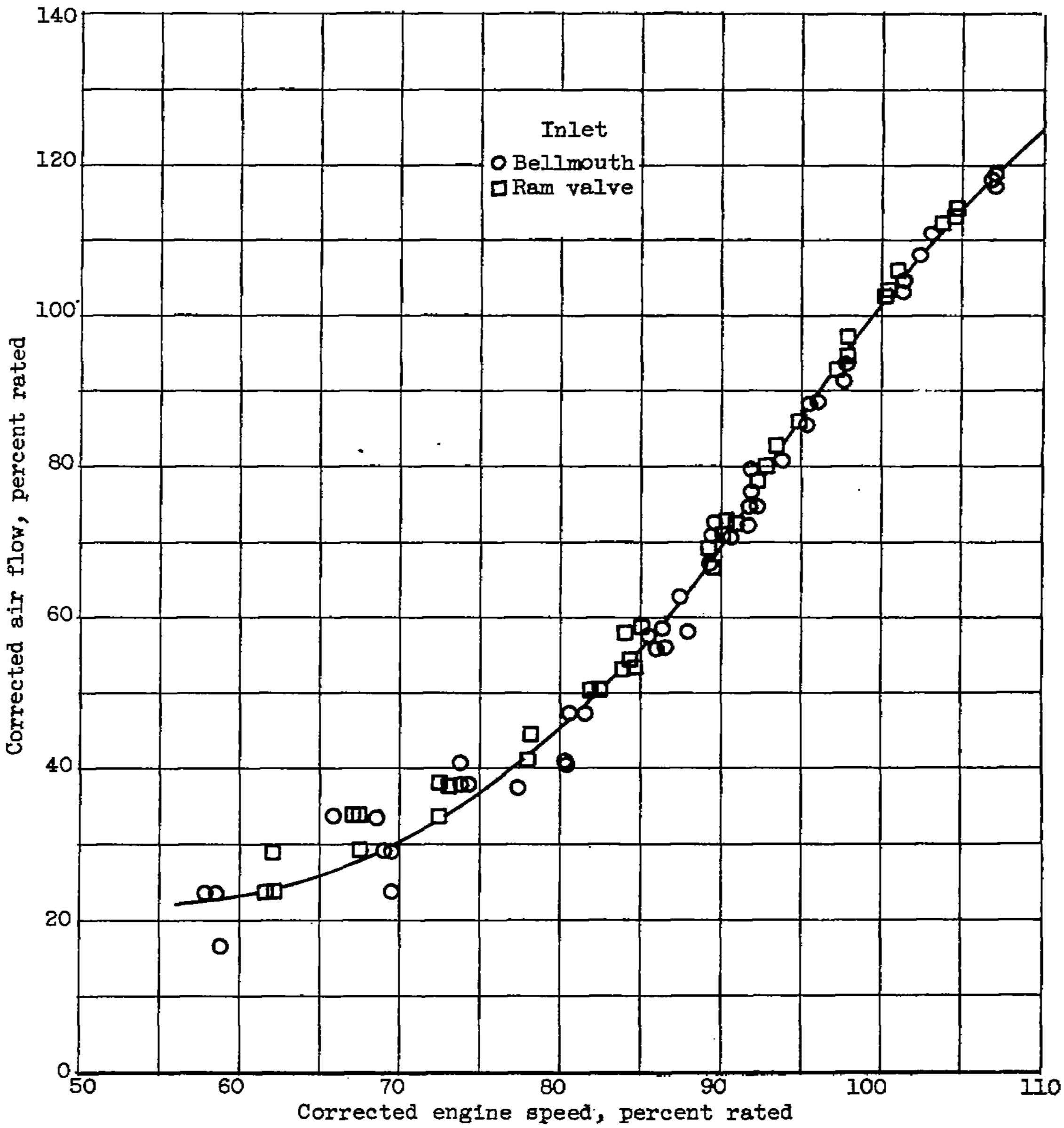

(a) Air flow.

Figure 5. - Effect of inlet configuration on steady-state engine operation. Altitude, 35,000 feet; flight Mach number, 0.2.

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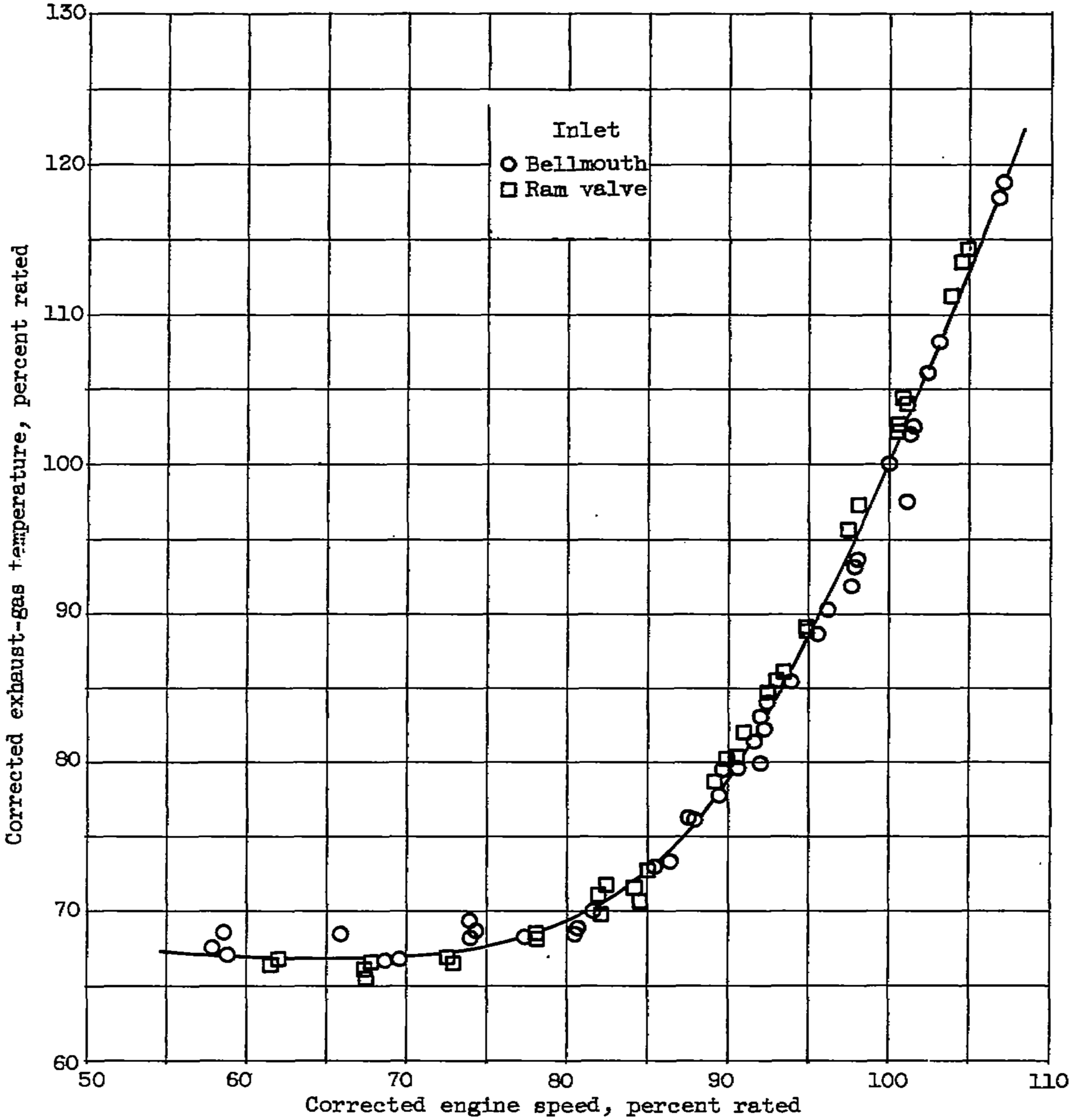

(b) Exhaust-gas temperature.

Figure 5. - Concluded. Effect of inlet configuration on steady-state engine operation. Altitude, 35,000 feet; flight Mach number, 0.2.

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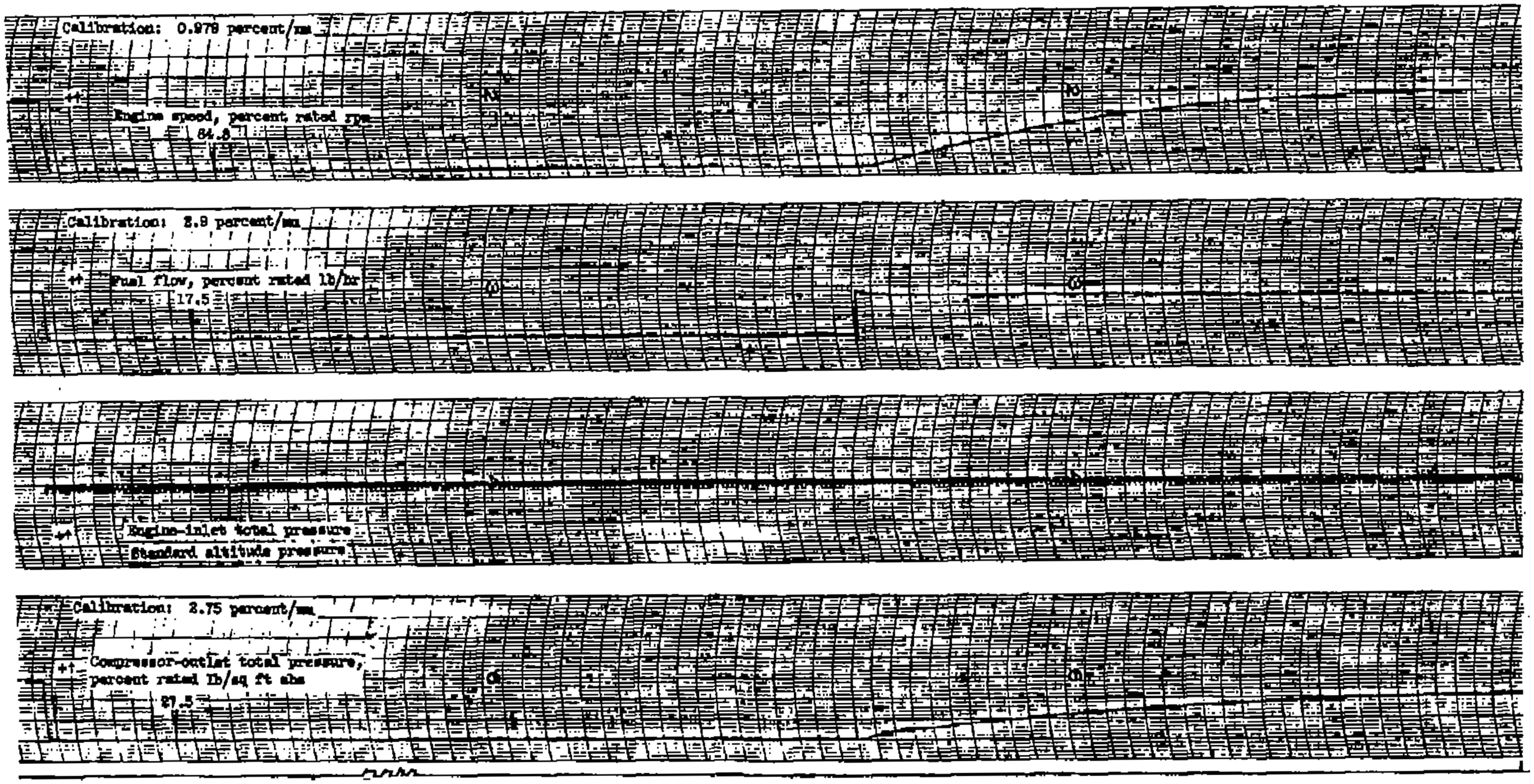

(a) Bellmouth inlet configuration.

Figure 8. - Response of engine variables to successful acceleration.

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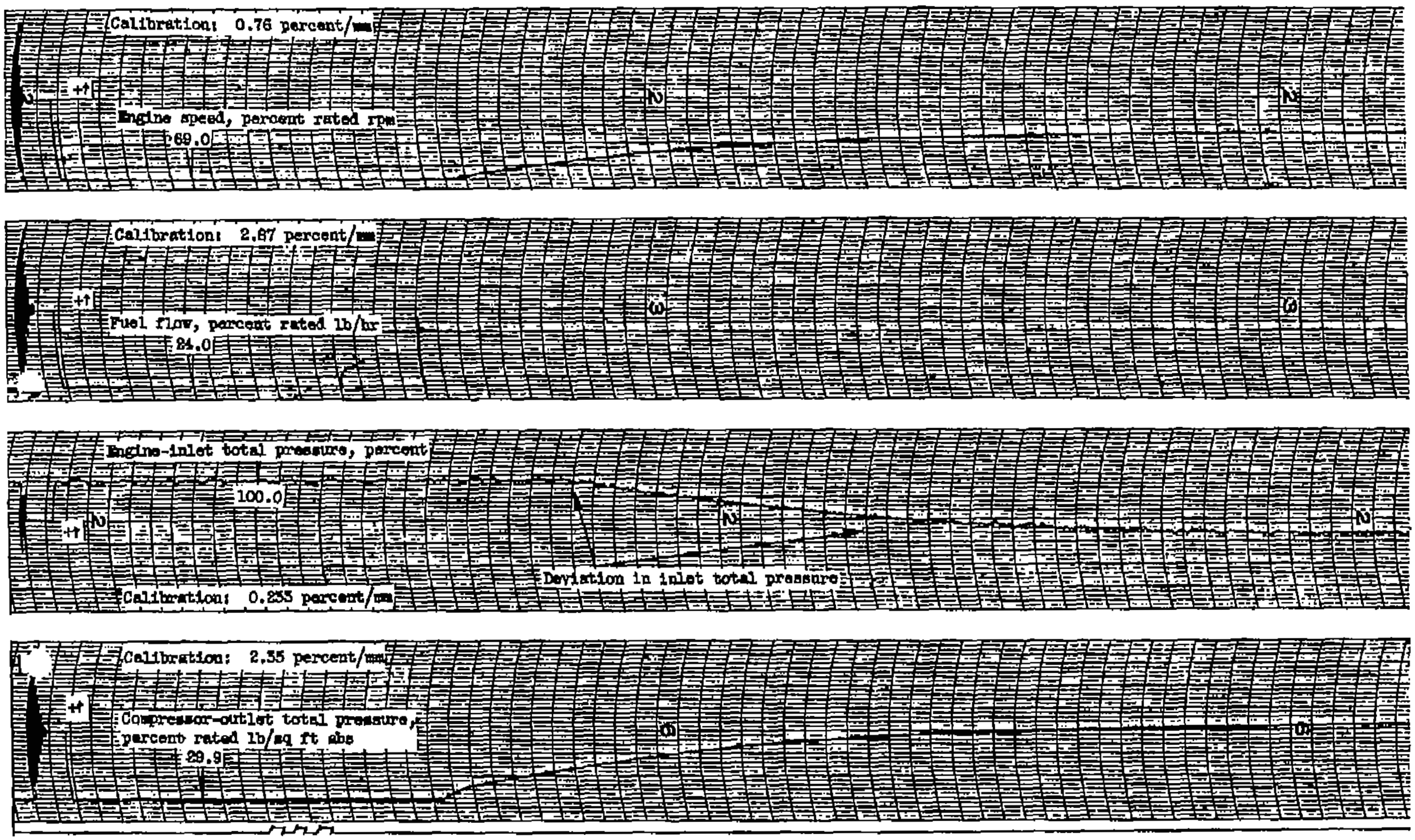

(b) Ram valve with proportional control.

Figure 6. - Continued. Response of engine variables to successful acceleration.

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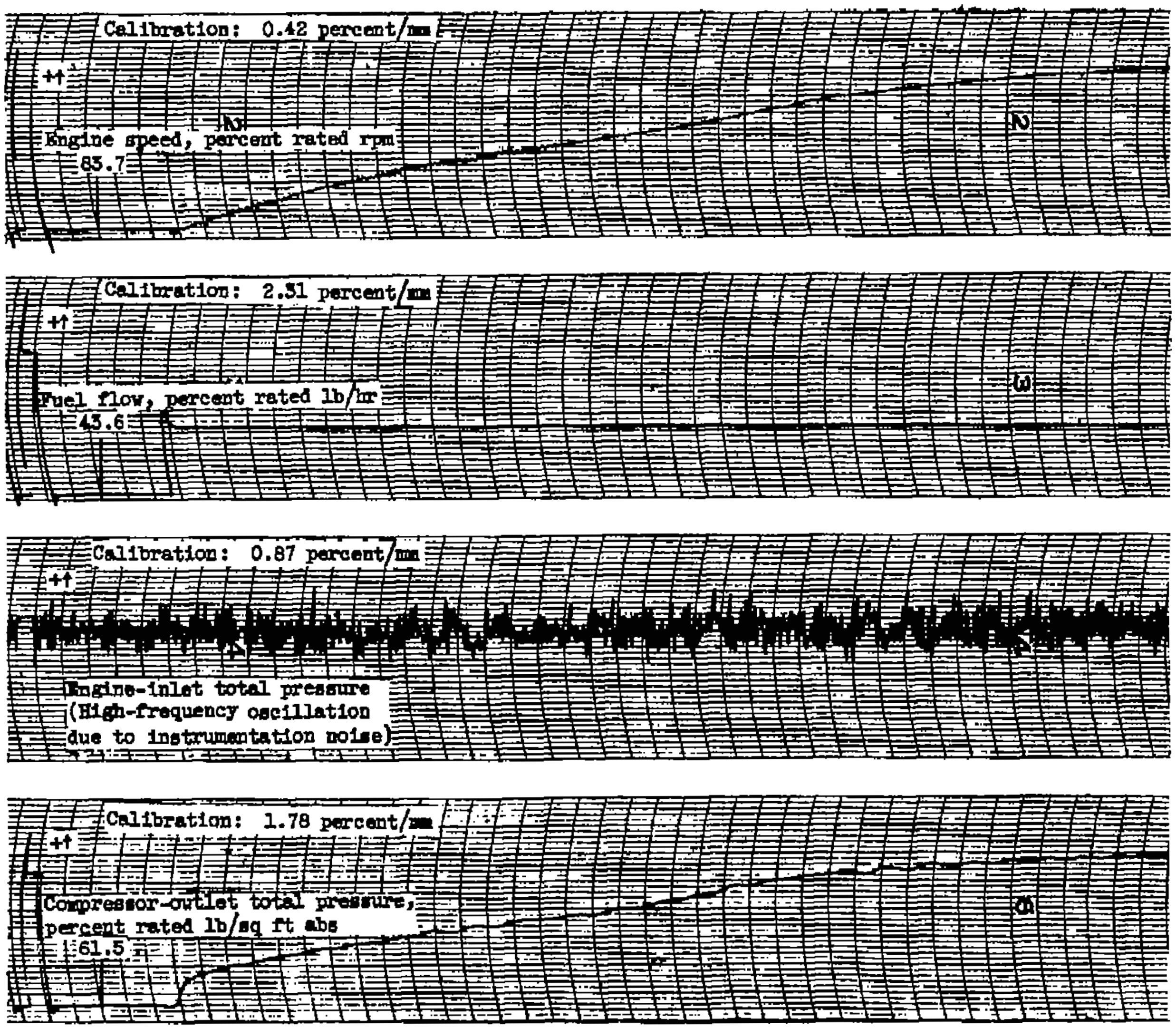

(c) Ram valve with proportional-plus-integral control.

Figure 6. - Concluded. Response of engine variables to successful acceleration.

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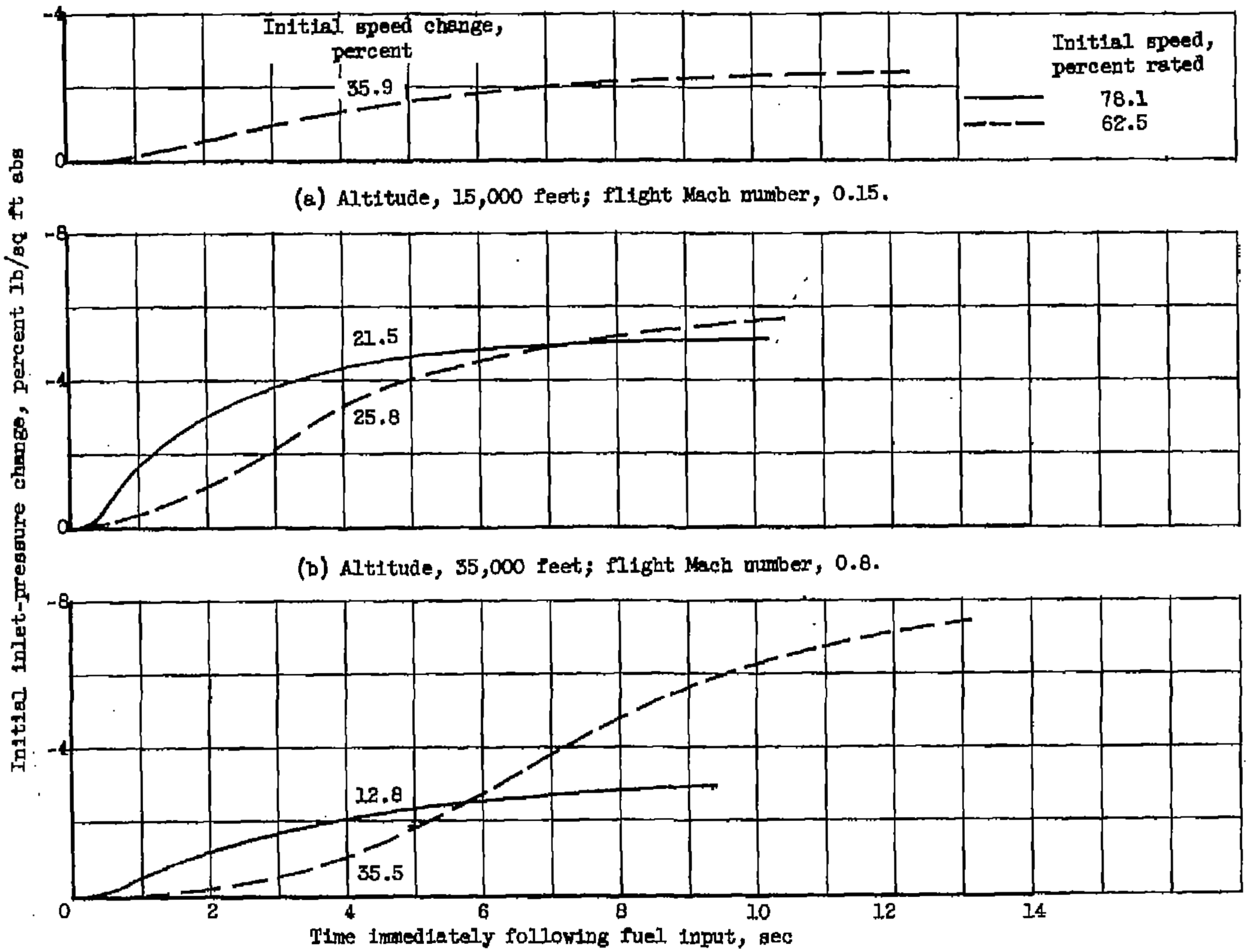

(a) Altitude, 15,000 feet; flight Mach number, 0.15.

(b) Altitude, 35,000 feet; flight Mach number, 0.8.

(c) Altitude, 50,000 feet; flight Mach number, 0.8.

Figure 7. - Inlet-pressure deviations for several successful accelerations with constant-inlet-pressure valve proportional control.

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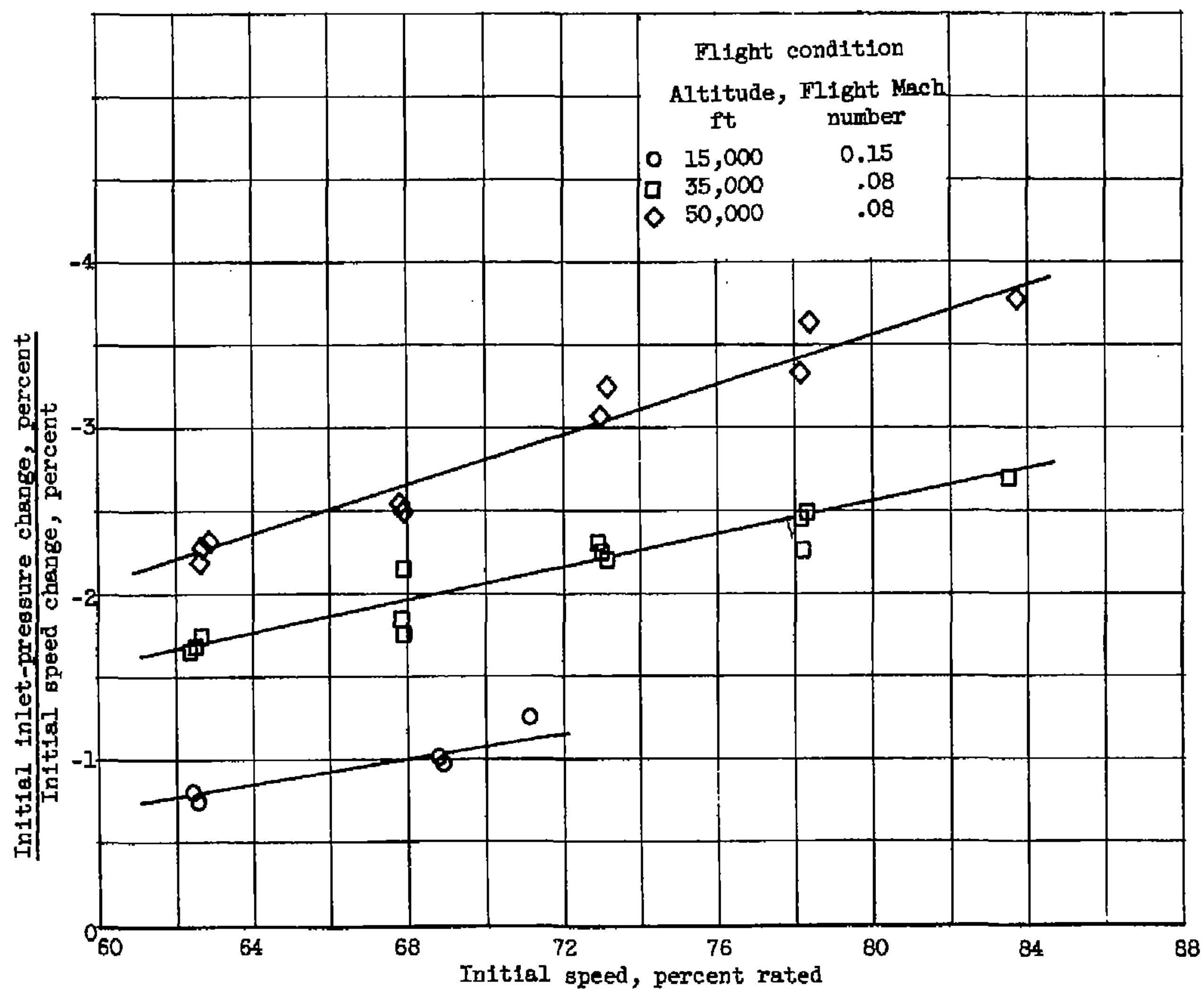
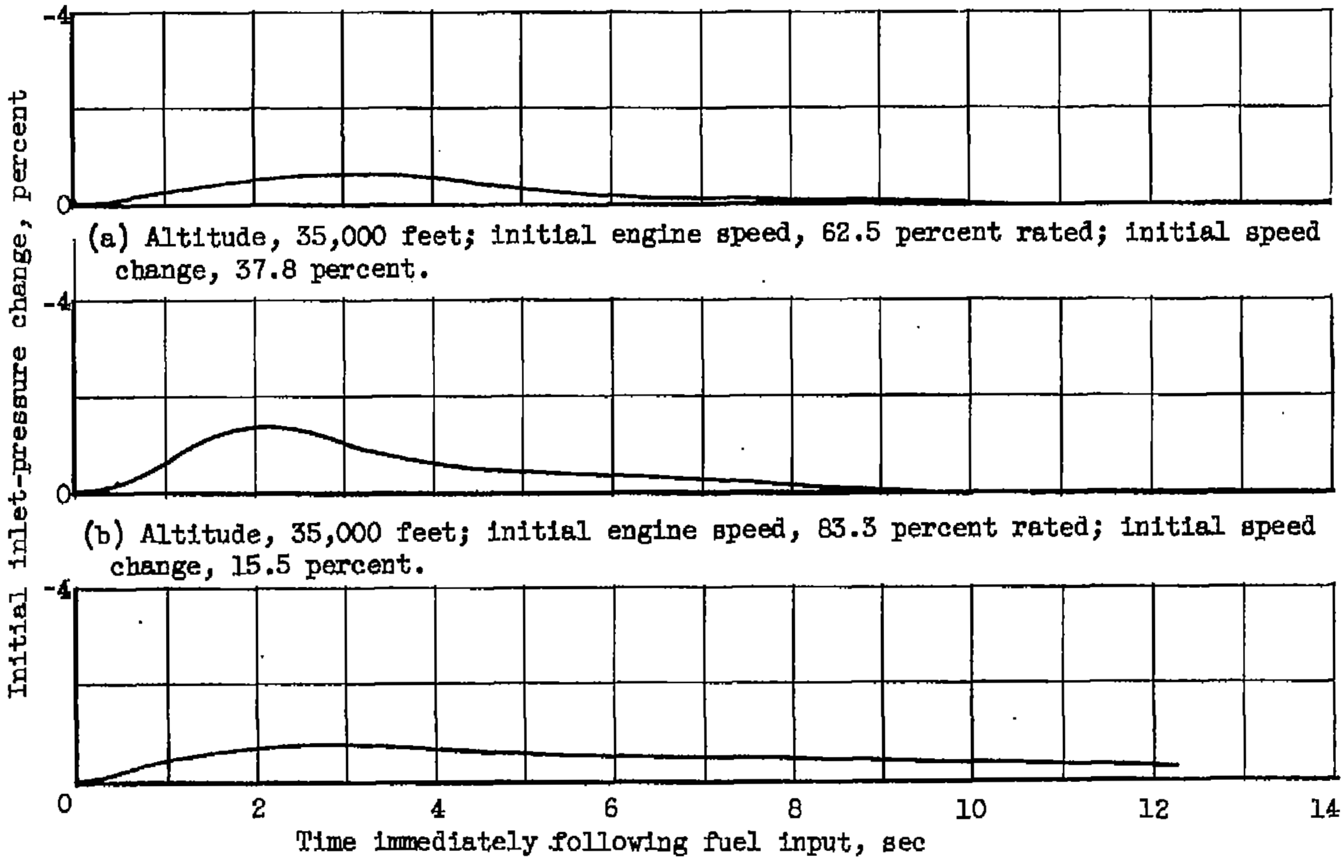


Figure 8. - Relation of inlet pressure and initial speed change during acceleration with initial speed. Proportional control.



(a) Altitude, 35,000 feet; initial engine speed, 62.5 percent rated; initial speed change, 37.8 percent.

(b) Altitude, 35,000 feet; initial engine speed, 83.3 percent rated; initial speed change, 15.5 percent.

(c) Altitude, 50,000 feet; initial engine speed, 73.0 percent rated; initial speed change, 12.2 percent.

Figure 9. - Inlet-pressure deviations for several successful accelerations with ram valve. Proportional-plus-integral control; flight Mach number, 0.8

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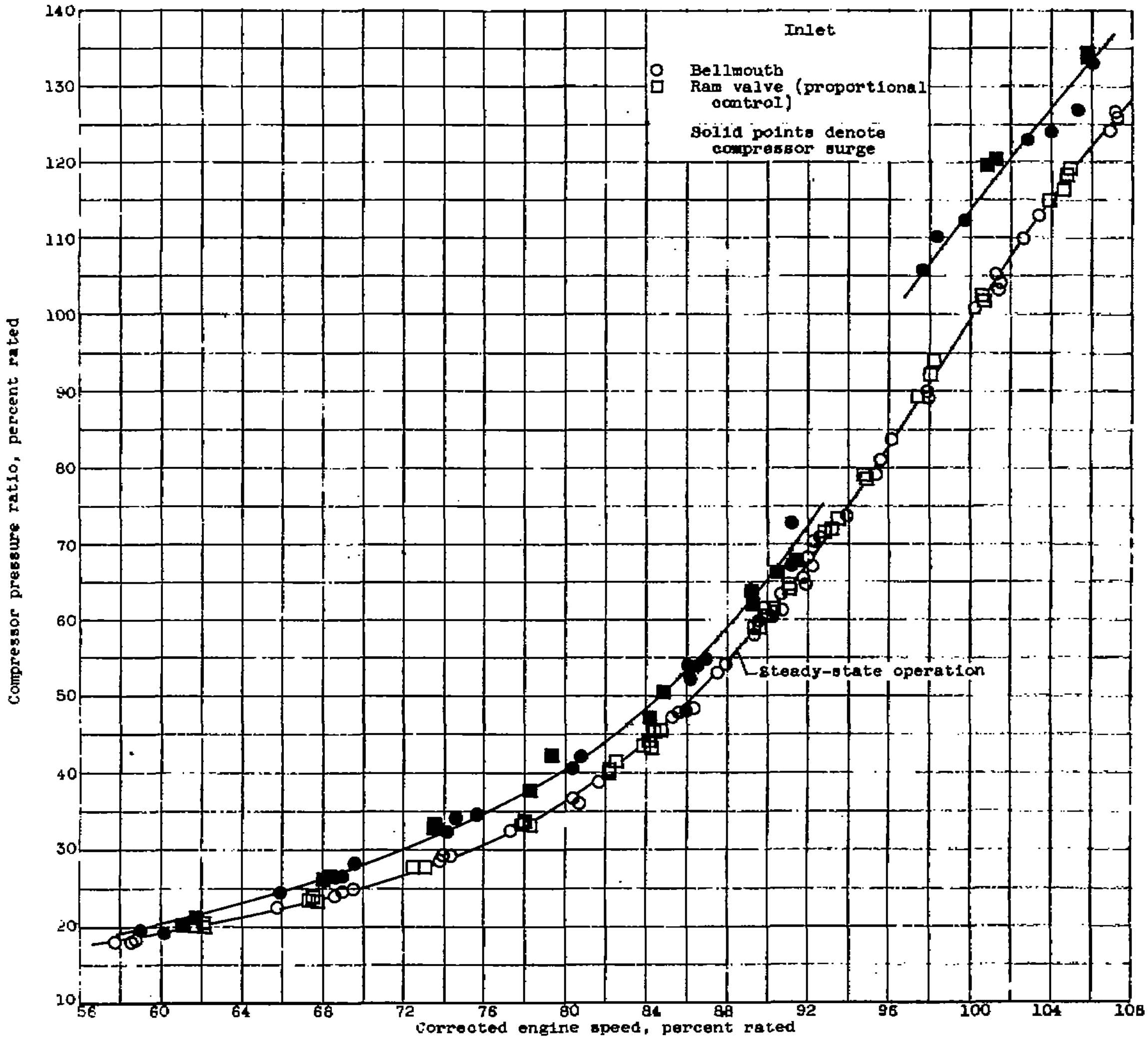

(a) Compressor pressure ratio.

Figure 10. - Comparison of steady-state and stall characteristics for two compressor-inlet configurations. Altitude, 35,000 feet; flight Mach number, 0.2.

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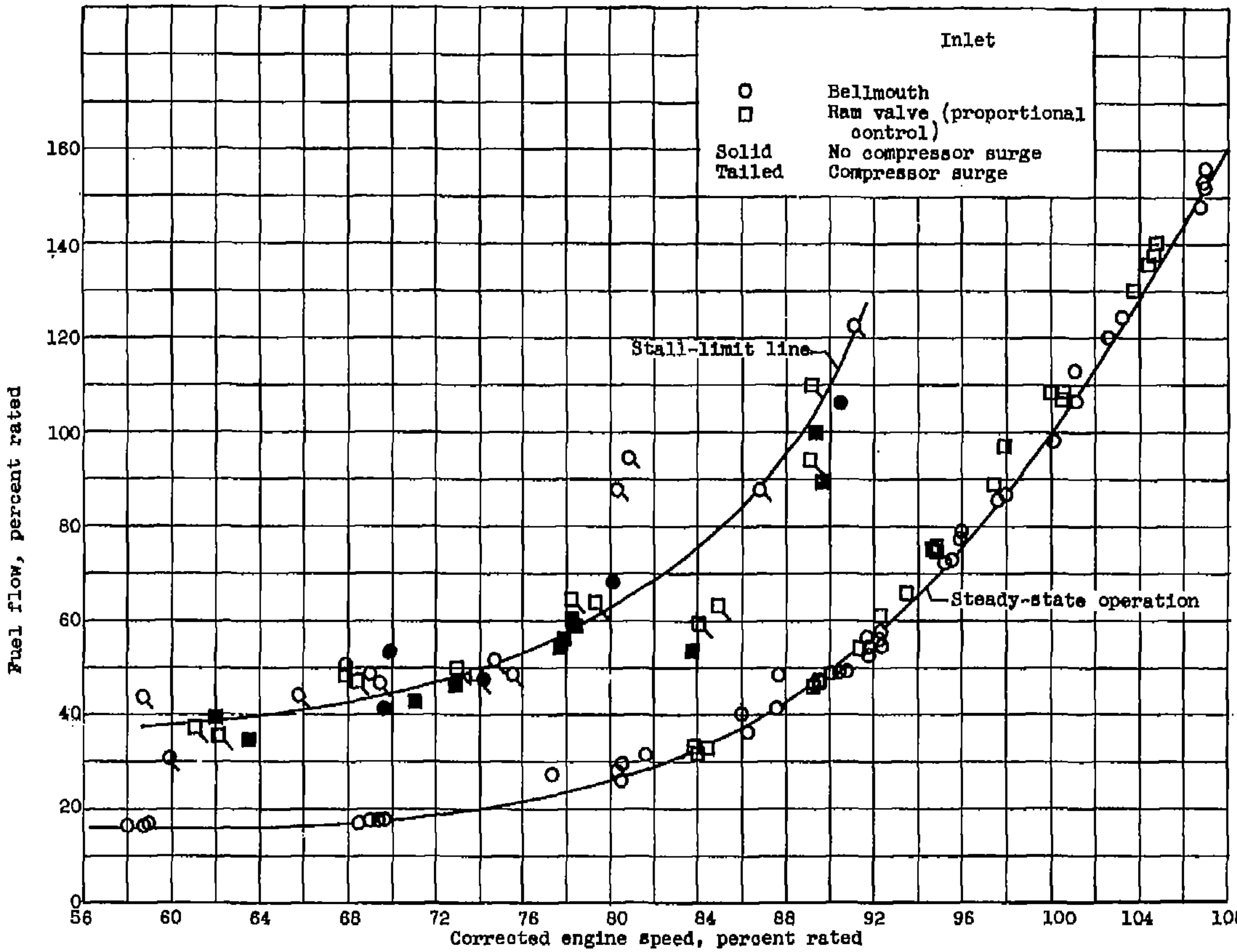

(b) Fuel flow.

Figure 10. - Concluded. Comparison of steady-state and stall characteristics for two compressor-inlet configurations. Altitude, 35,000 feet; flight Mach number, 0.2.

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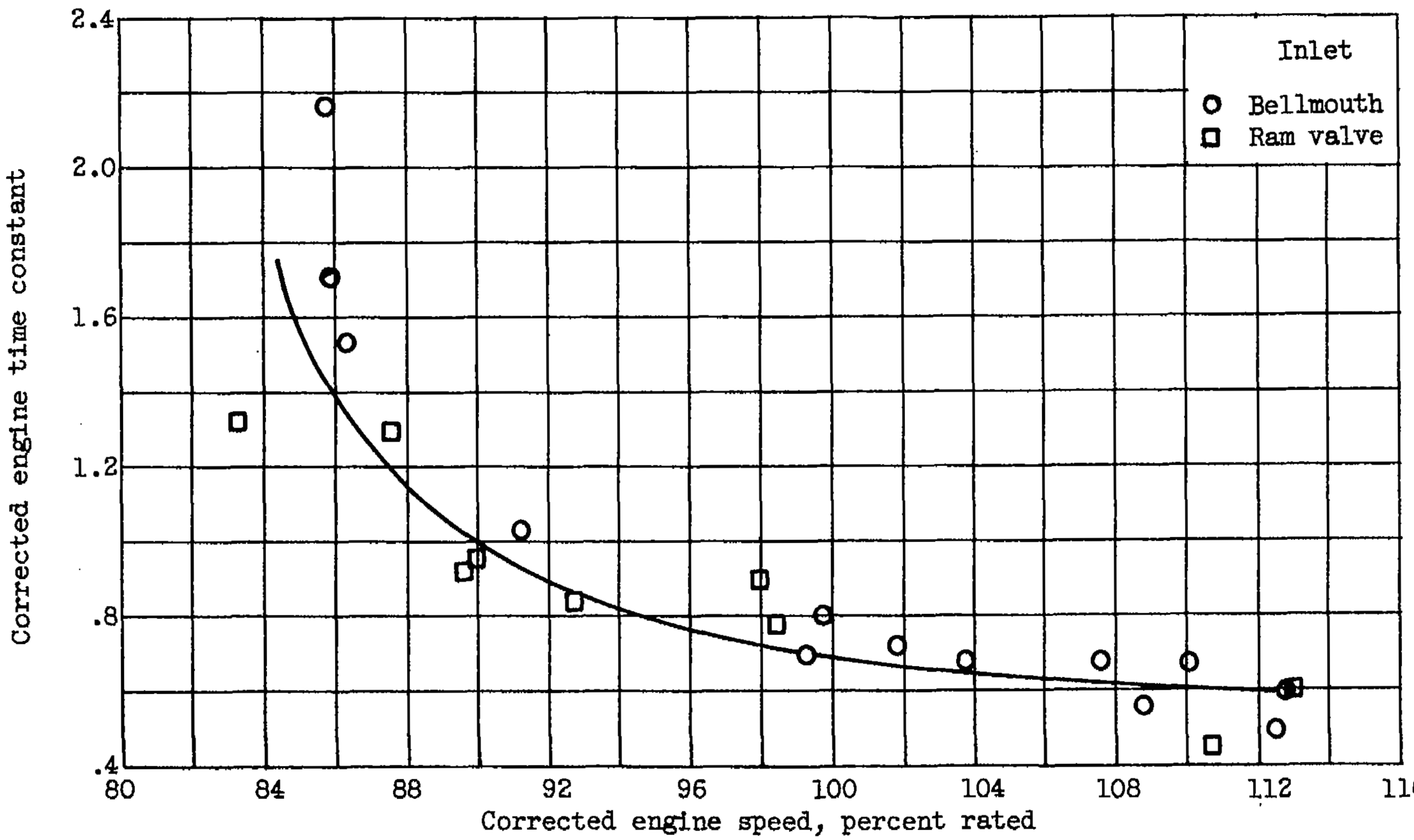
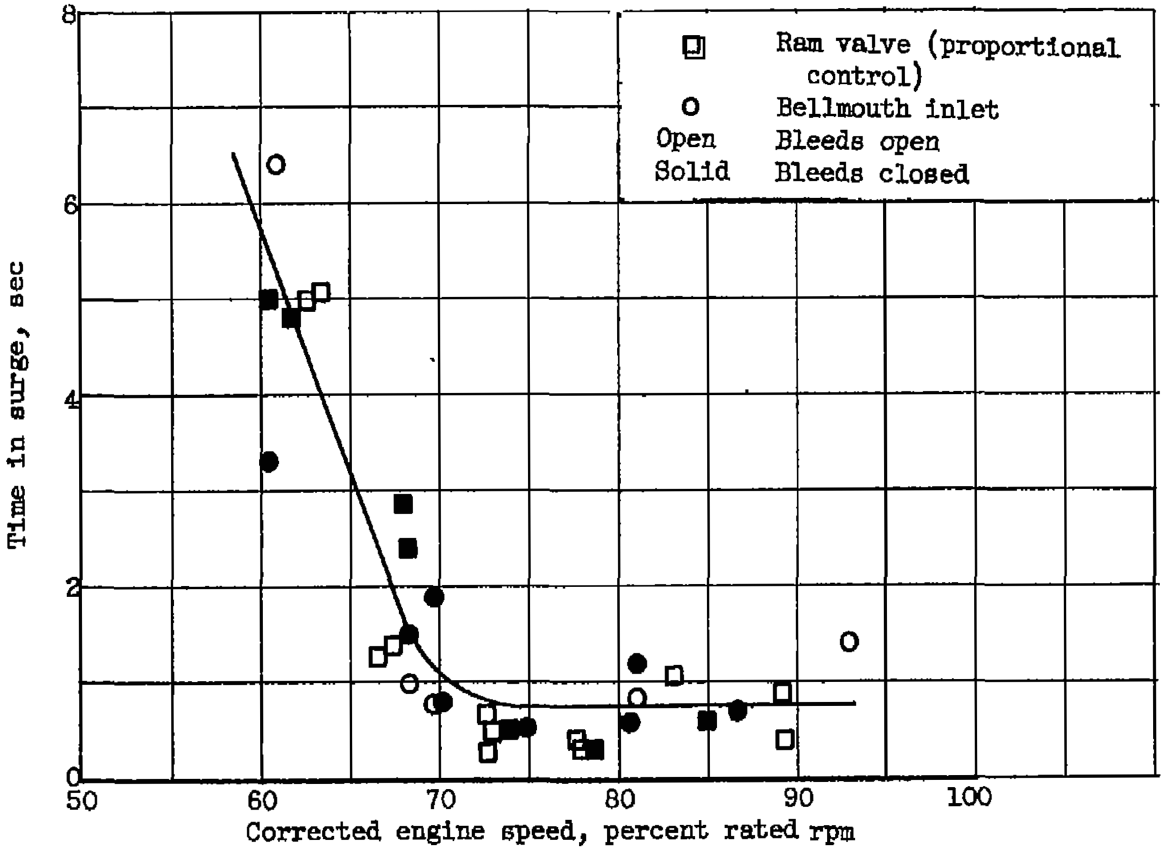
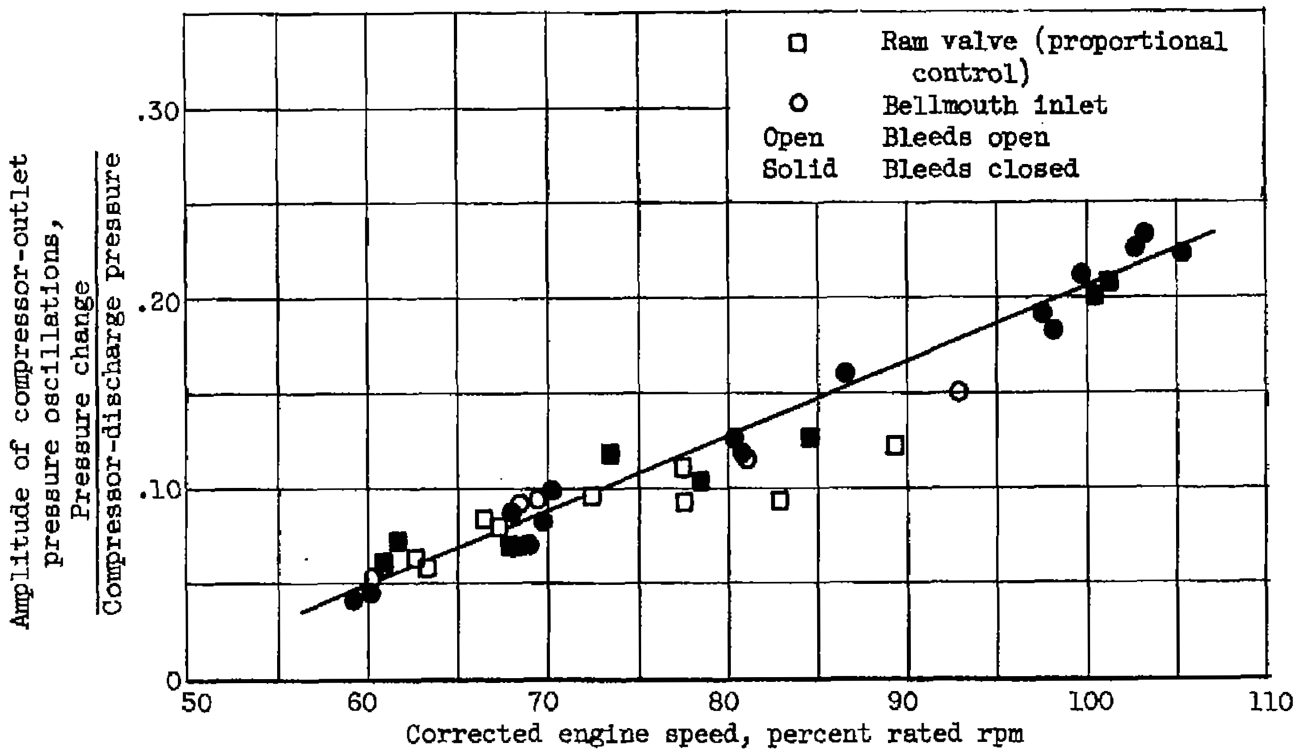


Figure 11. - Effect of inlet-duct configurations on corrected engine time constant. Altitude, 35,000 feet; flight Mach number, 0.2.



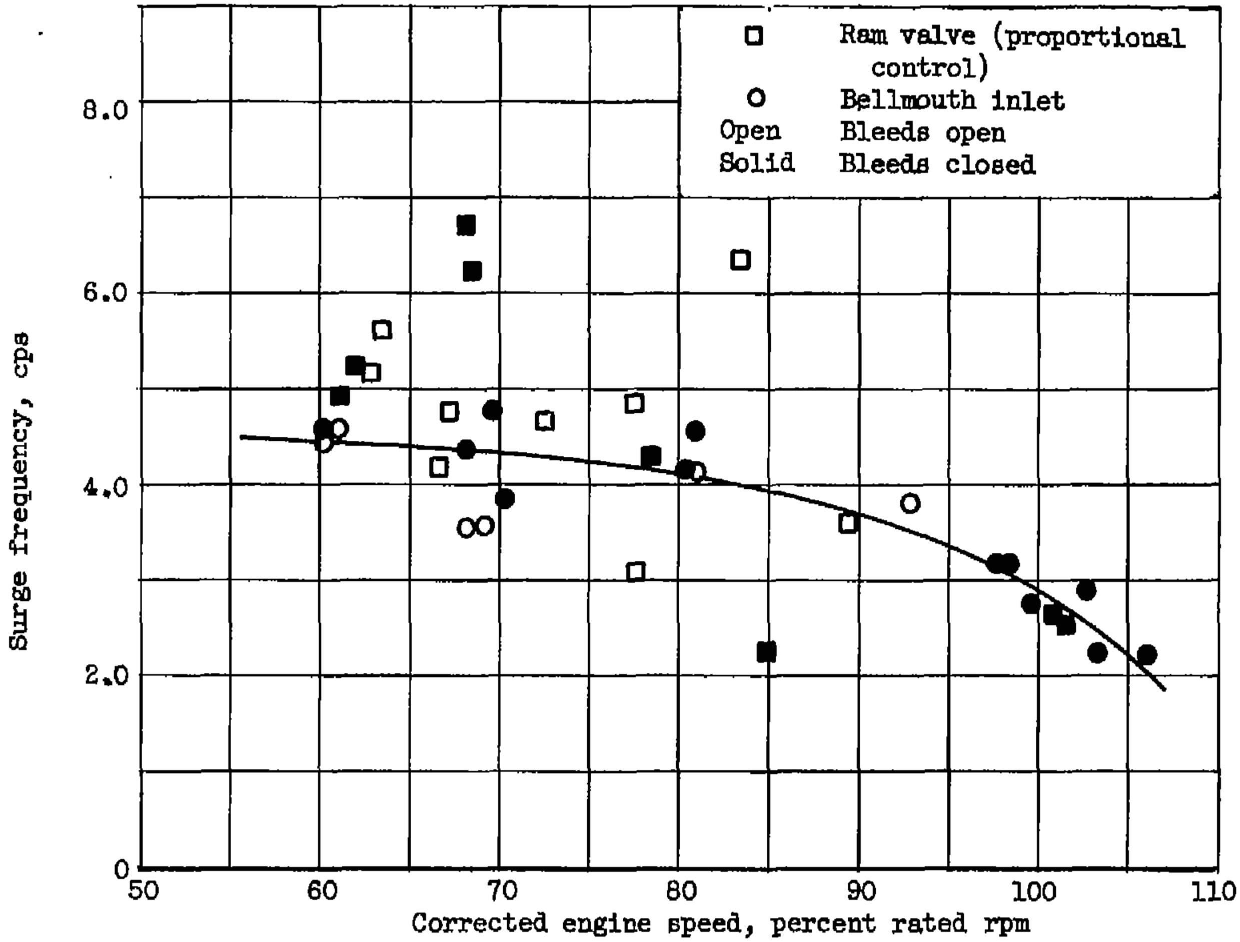
(a) Time engine remained in surge condition.

Figure 12. - Effect of inlet configuration on compressor surge.



(b) Compressor-outlet pressure oscillations during surge. Altitude, 35,000 feet; flight Mach number, 0.2.

Figure 12. - Continued. Effect of inlet configuration on compressor surge.



(c) Engine surge frequency. Altitude, 35,000 feet; flight Mach number, 0.2.

Figure 12. - Concluded. Effect of inlet configuration on compressor surge.